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Interdisciplinary approaches to understanding and preserving mudbrick architecture in regional and diachronic contexts

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Abstract: Mudbrick is a challenging material to interpret, maintain, and preserve in terms of planning and treatment decision-making—especially when recovered during archaeological excavation. Further challenges exist where mudbrick remains have been exposed and abandoned, as interactions with the environment (especially water and wind) introduce additional dissolution and damage of the resource. In this paper, we present multidisciplinary research focused on the interpretation and preservation of ancient and vernacular mudbrick architecture in the Marmara Lake Basin in western Turkey. Of interest is the preservation of mudbrick and stone foundations at Kaymakçı, a Middle to Late Bronze Age, ridge-top citadel. We demonstrate that utilizing multiple lines of evidence, including macromorphological, mineralogical, and chemical studies interpreted within the context of extant vernacular traditions in the region, produces a nuanced understanding of the archaeological evidence. Further, ethnographic and experimental archaeological research with local stakeholders allows for the development of a robust template for testing

ABOUT THE AUTHOR

Caitlin R. O'Grady All authors are members of Gygaia Projects, a research collaboration led by Christina Luke and Christopher H. Roosevelt. Gygaia Projects focuses on the intersection of three primary interests—culture, nature, and community—in order to build collaborative partnerships to promote the active production of knowledge, the sustainable management of cultural and natural heritage resources, and community developments. Project activities focus on the basin of Lake Marmara, in the districts of Gölmarmara and Salihli, province of Manisa, western Turkey, with an onsite field laboratory. Cultural initiatives aim to document and help preserve the cultural traditions of the Marmara Lake basin of the Gediz Valley in Turkey from the Paleolithic to the present. Archaeological fieldwork under the Central Lydia Archaeological Survey (CLAS) and the Kaymakçı Archaeological Project (KAP) explores human–environmental interactions from the deep past through the early twentieth century, while regional ethnography and oral histories of the recent past and present provide contexts for long-term landscape histories.

PUBLIC INTEREST STATEMENT

Efforts to preserve archaeological resources are complicated by competing economic interests (e.g. agriculture, road and habitation construction, etc.) in many regions of the world including the Gediz Valley in western Turkey. This article presents research that facilitates the preservation of archaeological resources by linking mudbrick architectural practices of the past with enduring contemporary traditions in the region. The development of direct partnerships with local stakeholders enables continued safeguarding of archaeological remains by recognizing their knowledge, expertise, and role in the analysis and conservation process. Development of these collaborative relationships assists local communities and provides necessary data for archaeological and preservation policies—which are fundamental to local, regional, and national governments.

and implementing sustainable site-preservation strategies for *in situ* architecture with immediate communities.

Subjects: Materials Science; Culture; Heritage Management & Conservation; Archaeology

Keywords: mudbrick; conservation; Kaymakçı; western Turkey; archaeology; ethnography; vernacular architecture

1. Introduction

Over the past decade, Gygaia Projects—including the Central Lydia Archaeological Survey (CLAS) and Kaymakçı Archaeological Project (KAP)—has investigated ancient and recent mudbrick architectural remains and other features in the Marmara Lake Basin of the Gediz Valley in Turkey. Integrated analytical data results, collected through survey, experimental research, and excavation, provide substantial information regarding mudbrick architecture in the past and its continuing legacies in the present. The selection of specific raw materials and manufacturing techniques, as well as their use and degree of processing, directly informs our understanding of decision-making in the past (Love, 2013b; Schiffer, 2003). The level of degradation associated with extant archaeological materials has a significant impact on any research. Therefore, the degree of stability directly influences methodological approaches to the collection and safeguarding of data relevant to multiple (both present and future) audiences (Caple, 2004; Cooke, 2007; Özdoğan & Eres, 2012; Seeher & Schachner, 2014) and the selection of conservation intervention strategies following excavation (Barnard et al., 2016; Cooke, 2007; Fodde & Cooke, 2013; Friesem, Boaretto, Eliyahu-Behar, & Shahack-Gross, 2011; Friesem, Karkanas, & Tsartisidou, 2014a; Friesem, Tsartsidou, Karkanas, & Shahack-Gross, 2014b; Goodman-Elgar, 2008; Love, 2013a, 2013b). While variable preservation complicates our understanding of mudbrick architectural uses at Middle-Late Bronze Age Kaymakçı, we can understand better motivations and agency in the past by integrating data collected from contemporary vernacular practice.

Methodological approaches to the study of archaeological mudbrick frequently focus on the scientific assessment of materials and methods used in construction (Hughes, 1983; Love, 2012; Nodarou, Frederick, & Hein, 2008), or, ethnographic studies comparing recent use and abandonment practices with those documented in the archaeological record (Agorsah, 1985; Friesem et al., 2011, 2014a; Goodman-Elgar, 2008; Hassan Talebian & Ebrahimi, 2008; McIntosh, 1974). Scientific approaches utilize multi-instrumental techniques to characterize micro- and macroscale data to reconstruct past human activity regarding resource procurement, technological development, and organized labor practices within the context of building construction, as well as decision-making and meaning associated with architectural function. These interpretations require multiple lines of evidence that characterize raw materials including geochemistry of fabric and botanical/inorganic additives (Henn, Jacomet, Nagy, & Pal, 2015; Love, 2012; Nodarou et al., 2008); mechanical properties such as compressive strength and use-wear resistance (Morgenstein & Redmount, 1998); modifications upon exposure to high temperatures (Forget & Shahack-Gross, 2016); and brick shape and dimensions (Homsher, 2012; Love, 2012). Ethnographic approaches utilize a combination of field observations and laboratory chemical techniques to describe current mudbrick use (Agorsah, 1985; Hassan Talebian & Ebrahimi, 2008; McIntosh, 1974) and architectural abandonment (Friesem et al., 2011, 2014a, 2014b, Goodman-Elgar, 2008). These studies characterize observed degradation to provide insight into extant archaeological remains and human behavior (Friesem et al., 2011, 2014a; Goodman-Elgar, 2008; Hassan Talebian & Ebrahimi, 2008; McIntosh, 1974). While such work produces valuable insights connecting human activity in the archaeological and recent pasts, it rarely considers the use and potential impact of field treatments used to stabilize these materials and their associated data.

The preservation of mudbrick is challenging due to the inherent nature of the materials used in manufacture. Therefore, scholarship on the preservation of mudbrick and mudbrick architecture generally discusses a number of topics focused on deterioration, documentation, and treatment strategies by connecting technology, soil/sediment geochemistry, use/abandonment, degradation mechanisms, and long-term preservation through experimental testing of (ancient and new) mudbrick, as well as the application of conservation materials and interventions. These include identification and understanding of degradation mechanisms (Atzeni, Pia, Sanna, & Spanu, 2008; Balderrama & Chiari, 1996; Fodde & Cooke, 2013; Hadian Dehkordi, Vatandoust, Madjidzadeh, & Kashi, 2011) and documenting and assessing condition *in situ* (Barnard et al., 2016; Cooke, 2008). Publications also address the testing of conservation materials and methods including grout and mortar (Biçer-Şimşir & Rainer, 2011; Venkatarama Reddy & Gupta, 2005), wall capping using hard (Fodde, 2007a, 2007b; Fodde & Cooke, 2013) or turf-forming vegetative materials (Kent, 2013; Lim, Matero, & Henry, 2013; Miller & Bluemel, 1999), the installation of shelters and/or roofs (Matero & Moss, 2004; Mazar, 1999; Stubbs, 1995), and reburial (Balderrama & Chiari, 1996; Cooke, 2007; Demas, 2004; Goodman, 2002; Kavazanjian, 2004). These holistic efforts provide nuanced understandings of the manufacture, use, deterioration, and documentation of archaeological mudbrick, while enabling their ongoing study through long-term preservation.

In this article, we present a brief overview of mudbrick as a medium of construction and then discuss examples of both ancient mudbrick forms and uses from archaeological explorations. These are contrasted with recent mudbrick used in vernacular architecture of the middle Gediz River valley in Turkey as informed by in-field study and ethnographic documentation. Where possible, we tabulate mudbrick data collected from archaeological and ethnographic sites in the region using published and unpublished resources. We then report the methods and results of experimental field trials analyzing both contemporary and ancient mudbrick implementations, concluding with discussion of how combinations of ethnographic and experimental methods can help understand and prepare for the conservation of archaeological mudbrick remains.

Even though the preserved extent of mudbrick architecture at Kaymakçı is limited, it is highly desirable to preserve this material, given its place as the primary architectural building material. What is more, an understanding of the performance of the material in its local environment is a primary research goal. Mudbrick has been a popular building medium not only at the ancient site but also in the wider region ever since antiquity. This constitutes a long-lasting and traditional "vernacular" architecture in the Gediz valley, utilized widely until the 1960s, when changes in policies led to the abandonment of mudbrick structures in favor of new concrete buildings erected in the fertile lowlands closer to the Gediz River (Figure 1) (Luke & Cobb, 2013; see Soygenis & Kiris, 2009). Nonetheless, old mudbrick buildings continue to be associated with historical memory and a sense of identity among current communities of the region. In fact, the abandoned village of Eski Hacıveliler, close to the ancient site of Kaymakçı, continues to be such a focal point of belonging for the community that once inhabited it (Luke & Cobb, 2013).

2. Mudbrick: a primer

A mixture of sand, silt, clay, and organic and inorganic aggregates, mudbrick has been a popular building material for millennia. All these components are necessary to achieve desirable working and aging properties. Clay acts as a binding medium but is prone to contraction and cracking during drying, and sand is added to reduce shrinkage by providing a skeletal framework for clay particles. Organic temper, such as chaff and straw, increases tensile strength and makes bricks easier to manipulate when wet. Inorganic aggregates, including stone, calcium carbonate, and microartifacts, provide an additional structural scaffold (see Homsher, 2012; Houben & Guillard, 1994; Kemp, 2000; Love, 2012; Rosen, 1986 for variation in mudbrick recipes). The process of mixing, shaping, and drying mudbricks requires large amounts of water to create workable mud mixtures, while space is needed to dry formed bricks (for practical considerations with application to Late Bronze Age settings, see Seeher, 2007, pp. 35–43). Following mixing, wooden frames are used to shape mudbricks, which are left to dry thoroughly for days/weeks. In order to minimize transport logistics, mudbrick production is often located near construction locales. As mudbricks are prone to dissolution when wet, stone foundations often support mudbrick superstructures during construction. Mud plaster and render coatings protect walls from weathering and further water exposure.

Production and macrostructural characteristics differentiate mudbrick from pisé, another earthen building technology found frequently in Anatolian and Near Eastern architecture (Campbell & Baird, 1990; Hughes, 1983; Love, 2013a). In pisé construction, the mud mixture is poured and packed into *in situ* wooden frames/forms set up within the architectural feature itself, rather than being formed into individual bricks. The frames are often larger enabling more efficient construction, as pisé dries in place. The technology resembles the rammed-earth technique typical in ancient through modern East Asian architectural traditions (Fodde, 2009; Houben & Guillard, 1994; Warren, 1993).

The differential mixing of mudbrick components influences the mechanical and physical properties of the individual bricks including tensile strength, shrinkage, and cracking during drying. A degree of specialized knowledge is required to produce mudbricks within a specific environment through the selection of suitable raw materials (sediments, aggregates, water, etc.) and production locales with sufficient space to dry mudbricks. Mudbrick makers must have additional expertise to shape individual bricks and estimate appropriate drying times during construction, while also minimizing mudbrick degradation. Even though a community usually has access to a specific range of materials due to resource proximity, mudbrick recipes often vary. This variation reveals intentional production choices and construction preferences during all manufacturing phases and reflects a deep understanding of the surrounding environment, available resources, and local climate patterns, as well as the needs of the community. The study of mudbrick architecture, therefore, has the potential to yield information beyond resource management and labor organization, including wider community organization, identity, and their associated relationships. Such studies naturally focus on geographic areas where examples of both vernacular and ancient mudbrick architecture survive, evidencing continuity in manufacturing traditions.

3. Mudbrick in the Gediz Valley, Turkey

In Turkey, archaeological, historic, and contemporary habitation sites document mudbrick architectural traditions over several thousand years (Ramage, 1978; Roosevelt, 2007; Roosevelt & Luke, 2008, 2009, 2010, 2011, 2012, 2013). Archaeological evidence for the use of earthen construction is found at Sardis, located along the southern edge of the valley in the foothills of the Bozdağ (classical Tmolus) Range, and Kaymakçı, a site c. 18 km northwest of Sardis nearer the northern edge of the valley and overlooking Lake Marmara (Figure 1). Vernacular architecture in surrounding towns and villages such as Eski Hacıveliler and Tekelioğlu continues to make use of mudbrick construction. In the Gediz Valley, analysis of brick dimensions, composition, and assessment of brick color provide significant details regarding available resource selection and procurement, and manufacturing decision-making in the past and recent present, as well as evidence for a continuum of architectural traditions.

Raw materials used in earthen construction derive from the valley's local bedrock geology. Gneiss, limestone, marble, quartzite, schist, and slate are present as components of the Menderes Massif, which covers much of western Turkey and underwent varying degrees of metamorphism during the Precambrian or Late Paleozoic period (Luke & Roosevelt, 2009, p. 202). The foothills of the Bozdağ Range, as well as neighboring ridges and foothills that surround Lake Marmara (the classical Gygaean Lake), formed as a result of extensive Neogene faulting, which began sometime in the Miocene or Pliocene (Luke & Roosevelt, 2009, p. 202). This resulted in a variety of sedimentary deposits, notably the conglomerate on which Sardis was established. Sediments from ridges and foothills are degraded luvic leptosols (Gauthier, 2013), while soils in the valley consist of successive layers of alluvial, fluvial, and lacustrine facies (Hakyemez, Erkal, & Göktas, 1999). Both contribute to the silt, clay, sand, and carbonates typically found in sediments at ancient and contemporary sites in the valley (Hakyemez et al., 1999; Wilson, 1999).

When assessing archaeological and recent earthen architecture in this region, we have found that despite the use of similar raw materials, mudbrick recipes vary due to access to resources, required working properties, and desired aging characteristics. Bricks, as well as earthen material

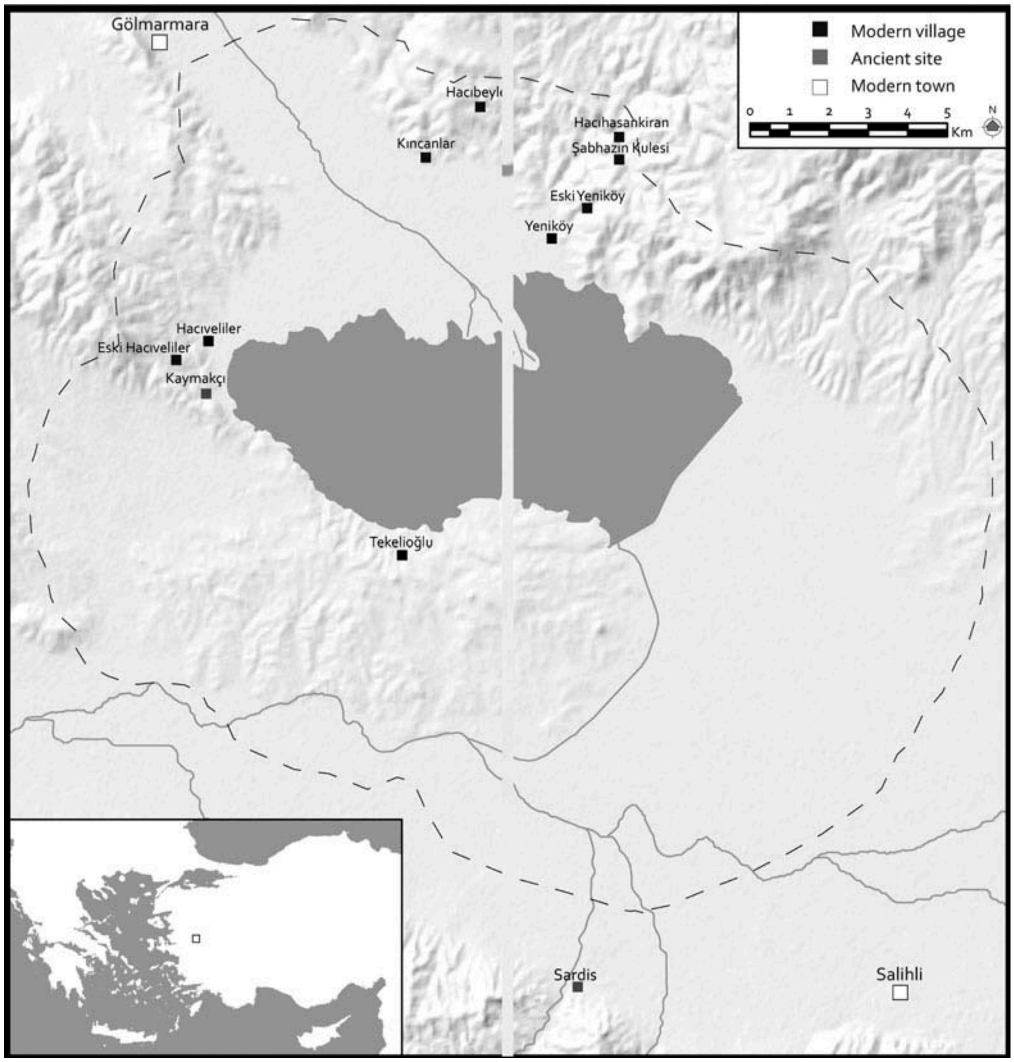

Figure 1. Map of Gediz Valley including locations of Kaymakçı, Eski Hacıveliler, and Tekelioğlu.

used in pisé architecture, consistently utilize local clay-rich sediments, though aggregate compositions may vary to include sand, thatch, straw, or other organic temper (Table 1).[1] While recipes vary, not all manufacturing steps are well defined. For example, many archaeologically recovered mudbrick samples from Kaymakçı show evidence of exposure to high temperatures, but the extent to which this is a deliberate part of manufacturing or the result of external events is unclear. There is evidence for industrial firing of mudbrick in contemporary vernacular architecture, even if it is limited to large population centers and production is characterized by significant failure rates during firing (Houben & Guillard, 1994). Mudbrick dimensions tend to be standardized and appear to be related to building/structure function or chronology. However, to understand the role of mudbrick architecture in the Gediz Valley, one must consider its continuum of use from the archaeological past to the contemporary present.

3.1. Ancient mudbrick in archaeological architecture

3.1.1. Sardis

Ramage (1978) was the first to study mudbrick architecture in the Gediz Valley, recovered as part of the excavations conducted by the Archaeological Exploration of Sardis, which investigates the capital of ancient Lydia. Published examples derive primarily from Iron Age (8th through 6th centuries BCE) household contexts (Ramage, 1978). Subsequent excavations

Table 1. Regional mudbricks from the middle Gediz Valley: size, color and temper based on data collected by Ramage (1978) and CLAS-KAP (Roosevelt and Luke, 2007, 2008, 2009, 2010, 2012)

Location	Color	Size (length x width x thickness)	Temper
Kaymakçı	Varies and dependent on exposure to the elements, high temperatures and/or the accretion development due to burial, but typical color profile is 5YR 6/4 -7/5YR 5/4	0.320–0.345 m x 0.078–0.084 m x 0.084–0.088 m	Thatch/straw
Sardis, HoB	No reported color profile	ca. 0.40 x 0.25 m x 0.08–0.10 m (Ramage 1978: 5)	Limited gritty sand; mud from pisé
Sardis, PN	No reported color profile	ca. 0.40 x 0.25 m x 0.08–0.10 m (Ramage 1978: 5)	Limited gritty sand; mud from pisé; straw or other organic temper in bricks
Sardis, Fortification Wall	No reported color profile	Average: 0.50 m x 0.30 m x 0.12 m (Ramage 1978: 5)	Limited gritty sand; mud from pisé
Eski Hacıveliler	Varies and is dependent on exposure and degradation, but typical color profile is 10R 4/8	0.354–0.425 m x 0.0269–0.326 m x 0.118–0.165 m	Straw or other organic temper present
Tekelioğlu	Varies, but typical color profile is within the 10YR/ 7.5YR families	0.221–0.238 m x 0.142– 0.153 m x 0.072–0.082 m	Straw or other organic temper present

of an Iron Age fortification wall provided additional data regarding the persistence of architectural traditions (Greenewalt, 1978; Greenewalt, Rautman, & Meriç, 1986). The Roman architect and writer Vitruvius (2.3.3) is responsible for spreading the lore of "Lydian" mudbrick in text, and mudbricks have been, and continue to be, excavated in a variety of contexts.

Typical Iron Age house construction at Sardis used a socle, or stone foundation, set into the ground with a mud mixture. Buildings consisted of a mudbrick superstructure built on the socle, while mud mortar secured alternating courses of mudbrick faced with smooth mud plaster—preserved on house walls in at least one case (Ramage, 1978, p. 5). In addition, there is evidence for pisé methods of construction resulting in preserved long, single foundational courses. Mudbricks used in domestic structures include straw as a binder, which is particularly visible in burned examples; pisé, alternatively, contained almost no straw—similar to bricks typically used in larger constructions such as the fortification wall (Ramage, 1978, p. 5). Mudbrick dimensions at Sardis range in lateral width of ca. 0.40 by 0.25 m and 0.08–0.10 m in height in domestic contexts, while those from fortification-wall contexts range in size from 0.50 by 0.30 m in lateral width and 0.10–0.12 m in height (see Table 1) (Ramage, 1978, pp. 5–6). Whereas there is no good evidence for timber framing in domestic architecture at Sardis, fortification walls incorporated wood for varying purposes (Greenewalt & Freedman, 1979, p. 23 and Fig. 28; Greenewalt, Ramage, Sullivan, Nayir, & Tulga, 1983, pp. 2–6; Greenewalt & Rautman, 2000, pp. 672–73 and Fig. 30). Unfortunately, Ramage (1978) does not report mudbrick color profiles making it difficult to determine if recovered samples show evidence of exposure to high temperatures.

3.1.2. Kaymakçı

While research at Sardis dates to the 1970s, investigations at the Middle to Late Bronze Age site of Kaymakçı (see Figure 1) began in 2012. Three years of excavation on site under the KAP provides critical information about the extent and nature of local mudbrick construction. Excavation and analysis of recovered material reveal evidence of older earthen architecture traditions dating to the second millennium BCE. Despite poor preservation characterizing most architectural evidence of mudbrick, increasing diversification of methods of investigation in recent years (e.g. Love, 2017) enables collection of new, meaningful information regarding production technology and choice. Archaeological data indicate that stone foundations and mudbrick superstructures define normative architectural traditions. While there is an extensive mudbrick corpus, there is limited archaeological evidence for *in situ* construction. The best-preserved evidence consists of two courses of mudbrick superstructure sheltered from postdepositional degradation and weathering by a fortification wall (Figure 2).

Figure 2. Two courses of mudbrick preserved *in situ* on top of stone socle recovered from Kaymakçı (KAP 97.545).

Preliminary assessments of individual or fragmented mudbricks help characterize their composition, manufacturing technique, use, and deterioration. In order to facilitate future analysis and comparative reference, inventoried samples represent the range and variation of mudbrick finds. Archaeologically recovered as fragments, mudbrick finds frequently preserve no more than 50% of the original brick size. The range of mudbrick types and shapes includes large, square bricks with lateral lengths of 0.320–0.345 m and heights of 0.078–0.084 m (see Table 1). Thinner mudbricks with heights of ca. 0.062 m are recovered in fragments—complicating final estimates of their original size. While it is clear that a number of standard brick sizes exist, their relationship to function or chronology is not clear. Color variation in mudbricks appears to result from sediment selection during manufacture, namely the varying ratio of sand, silt, and clay components. Brick exposure to high temperatures following manufacture and use in architecture also contribute to overall appearance. Surface color usually ranges between light reddish brown (5YR 6/4) to brown (7/5YR 5/4), while various shades of gray (10YR 6/2 to 7.5YR 7/2) also occur. Finally, owing to the volume of material and water needed for mudbrick production, we hypothesize that manufacture locales were situated near the settlement.

Mudbricks from Kaymakçı are rather heterogeneous in composition. Macroscopic and microscopic analyses provide detailed data regarding matrix composition and the nature and frequency of inclusions. Analyzed bricks incorporate aggregate, varying in size and composition, mixed with local iron (Fe)-rich sediments. Significant amounts of degraded micaceous schist and limestone (calcium carbonate—$CaCO_3$), and occasionally quartz, are present, while plant additives such as straw or chaff are preserved only as angular and/or subrounded voids. These mineral inclusions derive directly from local bedrock geology, supporting the hypothesis of local production, even if their proportions in individual mudbricks differ significantly. Furthermore, microscopic analysis reveals that Kaymakçı mudbricks exhibit a wide range of microstructures and degrees of sintering that impact overall porosity.

Fluctuating ratios of material components contribute to observed variation in mudbrick recipes rather than resource diversification. Disparities might stem from small-scale production units, wherein each used particular recipes and operated locally or for short periods to produce needed bricks for a particular housing block. Differential mixing within single batches of mudbrick may also be the source of variability. Currently, the relationship between mudbrick composition (whether homogenous or heterogeneous) and their geospatial location in individual walls or structures is unclear, as excavation has only revealed individual bricks rather than complete mudbrick courses. Whatever their origin, such variation is discernible in macroscopic and microscopic observation, as well as in particle-size analysis, which reveals high variation in sand and silt/clay component ratios (Figure 3). Following Love's (2017) methodology, field-laboratory analyses on sun-dried mudbricks used a nested set of sieves to distinguish between coarse (500 μm), medium (250 μm), fine (125 μm), and very fine (64 μm) sand, and silt/clay fractions and determine particle distributions. While "ideal" brick recipes usually contain up to 25–45% clay (Love, 2017, p. 354; Rosen, 1986), Kaymakçı mudbrick recipes diverge significantly from this ratio, a trend observed when comparing between bricks within the same architectural feature (Figure 3).

Post-manufacturing events also affect mudbricks recovered from Kaymakçı in addition to the observed decisions made regarding brick size, color, and composition. For example, many mudbricks have hardened due to contact with elevated temperatures, causing changes to brick microstructure and overall porosity. Exposure was either irregular (discerned by varying intensities of oxidation and reduction across the brick matrix cross-section) or consistent (characterized by an even light reddish-brown color across the matrix). In the absence of experimental field trials, it is difficult to determine if this exposure was intentional and part of the manufacturing process, occurred during use, or was the result of architectural abandonment processes (Lally & Vornarx, 2011). Our inability to distinguish between these processes stems from poor mudbrick preservation, itself a result of the site's shallow stratigraphy combined with anthropogenic (agro-pastoral) disturbances and natural (weathering) post-abandonment activities. In order to understand the

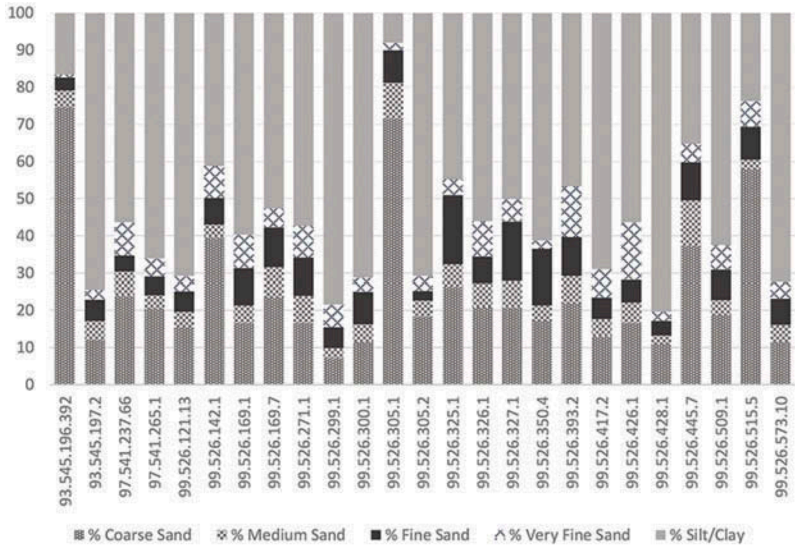

Figure 3. Percentage representation of sand and silt/clay particles in mudbricks from Kaymakçı.

events responsible for these modifications and their relationship to human agency, additional analysis, as well as comparison to vernacular use in the region, is necessary.

Most, but not all, mudbrick finds show evidence of surface accretions developed during weathering from air and wind exposure (see Figure 2). Many exhibit uniform calcium (Ca)-rich surface coatings ranging between 0.001 and 0.005 m in thickness, similar to those found on ceramic, stone, and bone artifacts excavated from the site. The presence of Ca-rich surface accretions confirms that, while the site is situated on/or near bedrock, the clay matrix of Kaymakçı soils retains moisture for extended periods. Exposure to substantial wind and water following abandonment is most likely responsible for weathering on mudbrick structures at Kaymakçı. This is analogous to observed damages associated with derelict modern structures preserved in the area today.

3.2. Mudbrick in vernacular architecture

Vernacular architectural traditions continue to use mudbrick throughout the Gediz Valley and Marmara Lake Basin—both located in western Anatolia (modern day Turkey). Studying current uses of materials and architectural forms has proved instrumental in understanding archaeological remains (Friesem et al., 2014a, 2014b, Goodman-Elgar, 2008). For example, Ramage successfully compared contemporary mudbrick architecture from the nearby and still occupied village of Sart to ancient mudbrick recovered from Lydian architecture at Sardis (Ramage, 1978), providing insight into the use and manufacture of excavated remains. Contemporary examples, either still in use or recently deserted, display varying degrees of alteration due to natural degradation and other post-abandonment processes. Examination of these alterations, thus, helps explain the appearance of and potential degradation mechanisms associated with mudbrick recovered during archaeological excavation of ancient sites.

The vast range of contemporary vernacular architectural forms in Anatolia has been categorized using a number of features related to location and function of rooms, construction techniques and materials, regional location, climactic zone, and/or ethnic or religious origin of the community (Asatekin, 2005, p. 391–396). Vernacular architecture in the Gediz Valley predominantly incorporates mudbrick structures with wood framing features built upon stone foundations. The adoption of fired and refractory mudbricks and concrete bricks is associated with changes in national building regulations (Soygenis & Kiris, 2009). Efforts to understand and interpret vernacular mudbrick architecture must consider a number of features that can be difficult to interpret in the archaeological record. Asatekin (2005, p. 400) notes that location and size of settlement, climate and other environmental features, economic conditions, inhabitant cultural and historic backgrounds, as well as social composition and structure are just as critical as the materials and manufacturing techniques used in construction. By defining these relationships and envisioning them in an architectural space, we can begin to promote meaningful discussions of archaeologically recovered architectural mudbrick remains.

3.2.1. Eski Hacıveliler

Systematic, intense, and diachronic survey of Ottoman and early Turkish Republican era settlements in the Marmara Lake Basin provide modern architectural mudbrick comparanda to architecture recovered at Kaymakçı (Roosevelt, 2007; Roosevelt & Luke, 2008, 2009, 2010, 2011, 2012, 2013; Roosevelt et al., 2018). These efforts, conducted under CLAS and before excavations commenced at Kaymakçı, identified Ottoman-period foundations of upland village communities that were uniformly vacated over the course of the twentieth century as part of one of the most dramatic shifts in settlement patterns the region has ever seen (Luke & Cobb, 2013). The pattern is most prominent on the northern fringe of the lake basin (see Figure 1), where settlements at Hacıbeyler, (Eski) Kılcanlar, Şahbazın Külesi, Hacıhasankıran, and (Eski) Yeniköy were abandoned, leaving mudbrick architecture standing in varying states of preservation (Roosevelt & Luke, 2011, p. 62). Just west of the lake, documentation efforts focused on the upland village of Eski Hacıveliler, located approximately 2.5 km from Kaymakçı up the Gür Dağ ridge, which was abandoned in the 1980s (see Luke & Cobb, 2013, Figure 1; Roosevelt & Luke, 2013). Given its nearby location and similar elevation, the deteriorated mudbrick architecture preserved is a viable living laboratory where degradation processes can be studied in close geographic relation to the ancient site.

Documentation of Eski Hacıveliler included collection of extensive oral histories of place, as well as an architectural survey to enable understanding of the Late Ottoman and early Republican periods in the region (see Luke & Cobb, 2013; see Figure 4). As part of the survey and documentation of the village, buildings and walls preserving extant mudbrick superstructures (greater than 1 m in height) were documented during brief periods of summer seasons between 2009 and 2010 (Roosevelt & Luke, 2011, 2012).

Most structures in Eski Hacıveliler have stone foundations, some with extant mudbrick superstructures, wooden support beams, and, where preserved, layers of plaster covering the mudbrick (Figure 4). Both single- and two-story residences are found in the village, allowing in the latter case for the demarcation of storage, social, and family spaces. Found predominantly in the lower village, single-story dwellings are oriented toward courtyards and enclosed by walls that close the structures from the street (Luke & Cobb, 2013, p. 164). Through interviews with Hacıveliler inhabitants, Luke and Cobb (2013, p. 164–6) highlight the importance of air movement, scent, and light in understanding how inhabitants organized and used their space. In addition, preserved sections of the buildings are extremely valuable documents recording the use of raw materials and manufacturing technologies used in construction through exposure of internal stratigraphic components. Therefore, mudbrick architecture from Eski Hacıveliler and its orientation/interaction with the surrounding environment inform our understanding of building function, as well as degradation and post-abandonment processes at Kaymakçı, in spite of observed differences between ancient and contemporary bricks.

Oral histories consistently report that local experts manufactured bricks using materials (mud, straw, and water) from sources within a kilometer of the village and exploiting local spring-fed water holes, while adjacent flat areas were used to bake bricks in the sun (Luke & Cobb, 2013, p.163). Eski Hacıveliler mudbricks incorporate large amounts of straw or chaff temper and coarse stone aggregate (namely schist and limestone pebbles) and show no evidence of exposure to high temperatures. These features are particularly evident on exposed and weathered samples. Typically, bricks are aligned in courses using mud mortar and preserve multiple plaster wall

Figure 4. Typical vernacular mudbrick architecture where mudbrick is laid across stone foundations and wood beams provide support; please note areas where original plaster surfaces are preserved, Eski Hacıveliler.

coatings, suggesting a frequent maintenance cycle. This differs from ancient mudbricks recovered from Kaymakçı, which incorporate a finer range of aggregate, lower percentage of organic temper, greater variance in standard brick size, and high-fire sintering (see Table 1 and Figure 2).

3.2.2. Tekelioğlu

Elsewhere in the Gediz Valley, the use of mudbrick in buildings has faded in recent years. This is due in part to national regulations of the 1930s through 1960s that mandated communities to abandon traditional mudbrick structures in favor of newer, cheaper construction materials including reenforced concrete (Soygenis & Kiris, 2009). Nevertheless, at the modern village of Tekelioğlu, a handful of contemporary practices necessitate continuation of mudbrick architectural traditions, especially for construction of bread ovens. According to local information, the manufacturing methods and material sources for such mudbrick features have changed little since the mid-twentieth century, and, as a result, utilize collective production knowledge. Preferred mud sources are located near perennial springs or wetlands, and sources for temper include locally available grasses and chaff. The addition of fine sand or small pebbles increases overall mudbrick strength and resistance to weathering and exposure. The continuing use of mudbrick in bread oven construction, especially, is associated with its perceived properties to produce more satisfactory results than modern materials including concrete or fired brick. By understanding sourcing and preparation of raw materials, as well as decisions made during manufacture, we can begin to interpret human motivations made during past occupations at Kaymakçı.

4. Preservation planning for archaeologically recovered mudbrick

Mudbrick preservation methodologies focus on several options—all of which aim at minimizing environmental impact through protective measures. These include (a) reburial (Balderrama & Chiari, 1996; Cooke, 2007; Demas, 2004; Goodman, 2002; Kavazanjian, 2004); (b) the installation of shelters and/or roofs (Matero & Moss, 2004; Mazar, 1999; Stubbs, 1995); or (c) wall capping (Fodde, 2007a, 2007b; Fodde & Cooke, 2013) using turf-forming vegetation (Kent, 2013; Lim et al., 2013; Miller & Bluemel, 1999). These methods are frequently utilized in tandem with the application of lime- or mud-based mortars and plasters, which are used to stabilize walls and minimize water infiltration through existing cracks or fissures (Charnov, 2011; Fodde, 2007a, 2007b) or new mudbrick skins to provide structural support for areas exhibiting coving (Fodde & Cooke, 2013; Fodde, Watanabe, & Fujii, 2011). These options can substantially alter the ways in which sites and architecture are seen and engaged by visitors, as well as the ways in which they are interpreted and used by stakeholders. Decision-making must include careful consideration of a number of competing goals including preservation, site presentation, research efforts, and interpretation.

Efforts to preserve and maintain newly excavated earthen architecture at Kaymakçı remain challenging. As excavation continues, conservation methods and treatment must navigate between architectural stabilization and preparation for tourist visitation, while developing a narrative that links the archaeological past with current ethnography. At its core, this approach synthesizes local knowledge and understanding of vernacular mudbrick architecture (Jerome, Chiari, & Borelli, 1999), human interaction with the environment (Hassan Talebian & Ebrahimi, 2008; Jerome et al., 1999), and experimental testing of conservation interventions in the field (Fodde, 2007a, Fodde et al., 2011, Matero & Moss, 2004).

At Kaymakçı, a number of preservation options are being investigated in order to develop solutions that facilitate an archaeological narrative while also considering existing human–environmental dynamics. The use of soft capping and mortar for mudbrick stabilization is particularly critical given the impact of the surrounding environment and prevailing wind/water erosion on site preservation. We are currently assessing the following strategies: protection of exposed architecture through the use of mortar and hard- and soft-capping, complete reburial with digital reconstruction presented in a visitor center, and partial reburial of architectural features enabling visitors to interact with specially curated components. As with all archaeological sites, variations in condition of recovered architecture will impact the selection/hybridization of proposed strategies.

Preservation planning for mudbrick architecture at Kaymakçı is contingent on a number of interrelated, but variable factors including brick composition and manufacture, as well as use, exposure, burial, and changing weather patterns in the Gediz Valley. Discussions with Tekelioğlu and Hacıveliler residents reveal an intuitive and phenomenological understanding that local weather affects mudbrick manufacture, use, and long-term resistance to physical and chemical weathering. During planting and harvest seasons (May–November), local farmers, frequently women, gauge the direction and force of storms (e.g. gale-force winds and torrential rains, often accompanied by hail) to estimate the relative intensity of wind, dust, and water damage generated in specific areas (Luke, Roosevelt, & Scott, 2017). Empirical observations regarding the predicted impact of weather events prove the accuracy of such methods. Torrential winter storms and catastrophic flooding occurred more frequently in the past prior to the completion of regional water infrastructure in the 1970s; they caused substantial damage to buildings and mudbrick features and are more hazardous for buildings and features of mudbrick (Luke & Cobb, 2013, pp. 167–68). Archaeologically recovered mudbrick underwent cyclic exposure and erosion following abandonment and, ultimately, burial, while freshly exposed materials will undergo similar sequences of weather events. Therefore, understanding these phenomenological concepts is critical for planning long-term and collaborative architecture and site preservation activities.

Successful collaboration in preservation planning at Kaymakçı, as well as other sites in the Gediz Valley, relies on the active participation of local stakeholders, clear communication, and production of mutually beneficial impacts for all participants. These impacts include support for archaeological research, heritage and landscape planning, and economic development through heritage tourism. For these reasons, local populations from surrounding villages (Hacıveliler, Tekelioğlu, and others) are important partners in preservation. Their detailed knowledge of local politics, agricultural and economic policies, as well as observations of short- and long-term changes to the local environment are critical for planning, implementation, and assessment of any preservation strategy (Luke, 2019). Furthermore, these local populations are the primary work force and staff who excavate. It is local support for protection and maintenance that will aid in the sustainability of archaeological sites, such as Kaymakçı. Efforts to build capacity through training programs in the region are assisted through participation from many partners.

To achieve these results, communication with stakeholders must rely on the use of colloquial terms to discuss the environment and its impacts on archaeological sites. Communicating metric climate data generated from a weather station on site (e.g. temperature, pressure, precipitation, and relative humidity) as meaningful evidence is less productive. While academic publishing and granting institutions are likely to require scientific data for research into understanding and conserving mudbrick (and such data are in fact available and used), opportunities to integrate local communities in off-season stabilization and maintenance practices are far more robust and meaningful when based on ethnographic perspectives of environment and place.

4.1. Experimental field trials in mudbrick preservation

Beginning in summer 2013, the project collaborated with local communities to document seasonal weather impacts on mudbrick and assess the efficacy of various preservation approaches. This work draws on two lines of evidence: (a) chemical, physical, and mechanical property data of local sediments and (b) local understanding of biodiversity and climate. By marrying these two forms of data, we are able to develop preservation activities that benefit a wide variety of stakeholders. At Eski Hacıveliler, Tekelioğlu, and Kaymakçı, experimental field trials tested local sediments for use in the manufacture of mudbrick, mortar, plaster, and wall-capping materials. Investigations focused on architectural stabilization through application of mortar in repointing and capping. We constructed an experimental mudbrick wall in order to test repointing and soft-capping strategies using locally available materials and native vegetation. Once applied to architectural features, we assessed the stability and resistance of respective methods as they naturally aged.

During the latter half of the field-testing, community stakeholders facilitated direct monitoring of the field-tested preservation methods. Individuals from Hacıveliler and Tekelioğlu were provided training in maintenance and documentation so that they could continuously record conditions during the months and year following the end of the project summer season. Monitoring included regular, weekly observations of capping materials and the application of moisture throughout the dry season to ensure controlled drying of mortar and capping materials. Once the winter rains began, direct monitoring was only required monthly. Local partners inspected preservation interventions to assess and digitally document condition, which they shared with project leaders via email, phone, or Skype™. In consultation with their observations, documentation, and oral reports, we adjusted maintenance protocols as necessary. These integrated protocols enabled better understanding of how treatments age over a 12-month weather cycle while at the same time engaged local communities in preservation monitoring. This process provided multiple opportunities for the collaborative development of preservation knowledge and skills through practical training. Furthermore, we hope our mutually beneficial collaborations in material preservation will form the basis for ongoing and future conservation work at Kaymakçı.

4.2. Sediment testing at Kaymakçı, Eski Hacıveliler, and Tekelioğlu

In order to understand sediment properties, rheological behavior, and chemistry, we compared samples from Kaymakçı (sterile), Eski Hacıveliler, and Tekelioğlu. Quantitative particle-size analysis (Love, 2017), qualitative "stickiness" testing (American Society for Testing and Materials (ASTM) International, 2010), and practical experience working with local sediments show that they contain significant amounts of clay, as is typical in areas of schist bedrock (Wilson, 1999). Preliminary liquid and plastic limit (ASTM, 2010) results confirm similarities between sediment samples indicating their high plastic limits and high clay content. Sediments used to make local, recent mudbrick incorporate deteriorated clay and aggregate derived from the underlying micaceous schist bedrock, as well as associated carbonates.

Salinity, conductivity, and pH data provide insight into the suitability of local soils for use in conservation mortars and grouts. The presence of soluble salts introduced through conservation interventions compromises the stability of archaeological materials in contact with them—in particular mudbrick (Caple, 2004, p. 159; Clifton, 1980, pp. 3–4)—while changes in pH can partially dissolve extant lime content in mudbrick, plaster, and masonry (Caple, 2004, p. 158). A combination of microchemical spot-tests (see Odegaard, Carroll, & Zimmt, 2005, pp. 100–125) and commercially prepared spot-test papers (Merck EMQuant® 10019–1 Sulfate Test and Macherey-Nagel Quantofix® Nitrate/Nitrite) identified the presence/absence of carbonates, chlorides, nitrates, phosphates, and sulfates. A EUTECH Instruments Oakton® ECTestr 11 Dual Range conductivity meter and Oakton® Waterproof Double Junction pHTestr® 30 measured sample conductivity and pH, respectively.

Analyzed soils are relatively consistent in terms of detected salts and tested positive for high levels of phosphates, perhaps a result of widespread pastoral herding (Table 2). Overall, soil salinity varies (average = 271.1, mean = 253.5, standard deviation = 77.9) but is relatively low across the site except in two excavation areas (98.531 and 108.522), where sampled ionic conductivity exceeds the standard deviation. All soil pH measurements were slightly alkaline (7.84–8.31), but close to neutral. The observed alkalinity is consistent with the degraded soils found in the foothills and ridges surrounding the Gediz Valley—possibly due to the contribution of carbonates. Kaymakçı soils exhibit a similar range of ionic activity when compared to samples tested from Eski Hacıveliler and Tekelioğlu (average = 294.8, mean = 296.0, standard deviation = 26.7). Further, these soils are also consistently alkaline (8.16–8.56—EH1, EH2, EH3) or close to neutral (7.78—T4). Given these characteristics, local soils from the site and surrounding villages are both suitable for conservation interventions provided they are sterile with organic matter and loose aggregate removed.

4.3. Stabilization methods: testing of mortars

During the 2013 season, prior to any excavations at Kaymakçı, Eski Hacıveliler field trials tested the durability and stability of architectural conservation grouts and mortars in order to assess their resistance to crack propagation, weathering, and water exposure. Selection of testing locations relied on prior survey of the village, as well as documentation and condition assessment of extant standing structures. Conservation experiments focused on the Eski Hacıveliler schoolhouse, a civic structure situated on a prominent ridge northeast of the village center. The building location replicates the altitude, exposure, and environment of Kaymakçı, and, as a civic structure, its selection minimized any impacts on privately owned buildings. Experimental mortars were applied to a fieldstone masonry wall surrounding the schoolhouse perimeter, and a mudbrick wall within the abandoned schoolhouse itself (Figure 5(a,b)). Over the following year, local stakeholders documented their condition in order to provide real-time understanding of stability and exposure.

Table 2. Summary of soil chemical analysis from Kaymakçı (KAP) excavation areas, Eski Hacıveliler (EH) and Tekelioğlu (T)

Location	Conductivity (µSiemens)	CO_2^{-3}	Cl^-	NO_3^-	NO_2^-	PO_4^{-3}	SO_4^{-2}	pH
KAP 81.551	224	Strong positive	Negative	10–25 mg/L	0–1 mg/L	Strong positive	200–400 mg/L	8.31
KAP 93.545	193	Positive	Weakly positive	Negative	Negative	Strong positive	<200 mg/L	8.18
KAP 95.555	283	Positive	Weakly positive	25 mg/L	0–1 mg/L	Strong positive	<200 mg/L	8.01
KAP 97.541	200	Strong positive	Weakly positive	25 mg/L	0–1 mg/L	Strong positive	Negative	8.15
KAP 98.531	359	Strong positive	Negative	0–10 mg/L	0–1 mg/L	Strong positive	<200 mg/L	7.86
KAP 99.526	317	Strong positive	Weakly positive	10–25 mg/L	0–1 mg/L	Strong positive	<200 mg/L	7.84
KAP 108.522	391	Strong positive	Negative	25 mg/L	0–1 mg/L	Strong positive	200–400 mg/L	8.27
KAP 109.523	202	Positive	Weakly positive	50 mg/L	0–1 mg/L	Strong positive	Negative	8.18
EH1	312	Negative	Weakly positive	25 mg/L	Negative	Trace reaction	Negative	8.16
EH2	280	Negative	Weakly positive	10–25 mg/L	Negative	Trace reaction	Negative	8.56
EH3	265	Positive	Weakly positive	0–10 mg/L	Negative	Positive	Negative	8.12
T4	322	Strong positive	Negative	0–10 mg/L	Negative	Positive	Negative	7.78

Figure 5. Eski Hacıveliler conservation laboratory testing sites: (a) fieldstone masonry wall (south side) surrounding the schoolhouse perimeter and (b) mudbrick wall (west side) from the schoolhouse.

In order to adopt sustainable practices, we investigated a number of recipes based on cement–, lime–, and cement–lime mixtures, given that hydraulic lime is difficult to procure. Tested mortars used locally available soils, collected from Eski Hacıveliler (EH1, EH2, and EH3) and Tekelioğlu (T4). Following instruction from local experts, sieving removed aggregate (small pebbles and rock), organic detritus, and other components from selected soils in order to produce a homogenous matrix for use in mortar recipes. Cement–, lime–, and cement–lime-based mortars were tested using different recipes to determine the most appropriate working and drying properties for use in repointing. All mortar recipes were prepared using water from the nearby fountain (çeşme) on site.[2]

We investigated rheological working and mechanical properties such as wettability, strength, crack resistance, texture, and color qualitatively in the field. Wettability was assessed via empirical assessment of the ability of a liquid to maintain contact with the mortar surface. A known volume of water was applied to the mortar surface and observations made about the shape and size of the water droplet with respect to contact angle, as well as any changes over time. Mortar strength was assessed via compressive testing in the field, while crack resistance was determined through documentation of crack formation including size, shape, and width during drying and following drying. Mortar texture and color were assessed in comparison to surrounding architectural components using a RM200Q Spectrum Colorimeter to record Munsell® colors. We will use the results of these tests in a second phase of experimental trials in order to finalize the selection of specific preservation methods for site conservation at Kaymakçı.

Following application, damp towels and plastic sheeting covered mortar to ensure slow drying over a 15-day period. Mortars were monitored twice daily with digital documentation and condition assessment. Following assessment, these areas were covered with remoistened towels for controlled drying. Local colleagues continued to document and remoisten testing sites between August 2013 and May 2014 documenting changes over time and assessing the impact of weather, human, or animal interactions. Following reports regarding damage from grazing sheep and recommendations from our collaborators, we decided to erect protective chicken wire fencing around the test site. Mortar applied to the schoolhouse mudbrick wall required less protection. This resulting archive of collected images enables a more detailed analysis of observed failures and the dynamics of change over time.

Overall, the mortar recipes tested on extant walls in the Eski Hacıveliler school complex are robust and have aged well since their application in July 2013—including both cement–soil and cement–lime–soil recipes. Very few cracks are visible, while staining associated with the application of lime mortars diminished over time. Following real-time exposure, the cement– (batches 1, 2, and 4), lime– (batches 8 and 12), and cement–lime (batch 10) mortars exhibited desired aging properties (see Table 3). These batches displayed very good color matching to *in situ* and original architectural components, excellent surface wettability, very good surface cohesion, and the

Table 3. Summary of observed rheological and aging properties of mortar mixtures

Batch No.	Materials	Proportions	Comments during mixing and application (very good > good > poor)	Aging characteristics (very good > good > poor)
1	Cement Soil EH2 (0–1 mm) Washed sand (0–5 mm)	3 (Cement):5 (soil EH2):12 (washed sand)	Good workability Good wettability Very good color match	No cracks Very good cohesive strength Very good color match
2	Cement soil EH1 (0–1 mm) Washed sand (0–5 mm)	3:5:12	Good workability Good wettability Very good color match	No cracks Very good cohesive strength Very good color match
3	Cement Soil EH2 (0–1 mm) Brick dust (0–5 mm) Washed sand (0–5 mm)	3:4:1:12	Good workability and wettability Very good color match	No cracks Very good cohesive strength Good color match (slightly pink)
4	Cement soil EH1 (0–1 mm) Brick dust (0–5 mm) Washed sand (0–5 mm)	3:3:5:9	Good workability Good wettability Very good color match	No cracks Very good cohesive strength Very good color match
5	Cement Soil EH2 (0–1 mm) Brick dust (0–5 mm) Brick dust (0–1 mm)	3:5:6:6	Good workability Water pools on surface and is not absorbed Color too red Brick aggregate too large	No cracks Good cohesive strength Poor color match (due to high brick dust content) Visible brick aggregate
6	Cement Soil EH2 (0–1 mm) Brick dust (0–5 mm) Soil 3 (0–1 mm)	3:5:12:2	Good workability Water pools on surface and is not absorbed Poor color match (too red) Brick aggregate too large	Minor cracks Good cohesive strength Poor color match (due to high brick dust content)
7	Lime Sand (0–5 mm) Brick dust (0–8 mm)	6:6:2	Poor workability and difficult to control (due to excess water in mixture) Visible staining Poor color match (too gray-pink) Brick aggregate too large	No cracks Good cohesive strength Poor color match Visible aggregate
8	Lime Sand (0–5 mm) Soil EH3 (0–1 mm)	6:6:2	Good workability Minor staining Good wettability Very good color match	No cracks Very good cohesive strength Staining diminished over time Very good color match
9	Lime Sand (0–5 mm) Soil EH3 (0–1 mm) Brick dust (0–1 mm)	6:6:1:1	Good wettability Minor staining Good color match (slightly pink)	Minor cracks Good cohesive strength Staining diminished slightly Good color match (pink)
10	Lime Cement Sand (0–5 mm) Soil EH3 (0–1 mm)	5:1:2:6:1	Good workability and wettability Minor staining Very good color match	No cracks Very good cohesive strength Staining diminished Very good color match
11	Lime Cement Sand (0–5 mm) Soil EH1 (0–1 mm) Brick dust (0–1 mm)	5:1:6:1:1	Some visible staining Poor wettability; water pools on surface Poor-good color match (too gray)	No cracks Poor-good cohesive strength Poor-good color match (too gragy)
12	Lime Sand Soil EH1	1:1:6	Very good workability and wettability Very good color match	No cracks Very good cohesive strength Very good color match
13	Lime Sand Soil EH1 Brick dust (0–1 mm)	1:1:3:3	Very good workability and wettability Good color match (red)	No cracks Very good cohesive strength Good color match (too red)

Batches 1–11 were applied to a stone masonry wall, while 12–13 were applied to a mud brick wall with extent plaster.

development of minimal to no cracks during drying and aging processes (see Table 3). Based on these results, we selected several mortar recipes for further testing to produce complementary grout mixtures. Ten recipes, using varying proportions of lime, aggregate, local soil, cement, and fluidizers, were evaluated informally. Future research will assess the top four candidates in terms of flow, shrinkage, separation, and adhesion (Biçer-Şimşir & Rainer, 2011).

4.4. Experimental mudbrick wall construction and monitoring in Tekelioğlu

Field-testing also included the construction of a mudbrick wall and application of a vegetative soft cap to investigate environmental impacts on mudbrick and stabilization techniques, as well as to observe degradation of a mudbrick structure in real time. With our local collaborators, we constructed a test wall on an elevated hilltop with fruit and nut tree cultivation on the northern side of Tekelioğlu, locally known as Pear Hill (Armut Tepe) that overlooks Lake Marmara. We used recycled mudbricks—originally used to construct a storage barn—made from local soils and straw temper. The L-shaped wall was oriented to the north and west to replicate wind and rain exposure at Kaymakçı.

Local collaborators argued that the first major rain would seriously damage or decimate a wall positioned in this direction—thus confirming our choice of exposure for analysis as well as local knowledge of climate conditions and architectural choices. During discussions, we explained that understanding interactions with the local environment was critical for understanding decisions made in the past, especially given the desire (or need) to live on the ridge top, and that the results will help to develop a sustainable preservation practice at Kaymakçı. The group also noted that placement of the test wall on exposed bedrock would act as a surrogate for a stone foundation.

Our local collaborators were instrumental in the collection of materials needed to construct the experimental mudbrick wall and identify appropriate vegetation for soft capping. Mud coatings applied between courses and used in the soft cap made use of local sediments collected from Tekelioğlu (T4). Prior to the construction of the wall, we cleared the site of ground vegetation to expose the bedrock and applied a mud coating (soil and water) to its surface. We laid four mudbrick courses and adhered them using the mud coating. The short L-shaped wall measured roughly a half-meter in height utilizing four courses of bricks where each layer was perpendicular to that below (Figure 6(a)). The drying process was documented daily to understand impacts on exposed vertical and horizontal surfaces. Following construction and controlled drying to prevent accelerated evaporation during the first week, the top of the wall was sealed using sediments and locally sourced vegetation in an experimental soft-cap system, which will be discussed in subsequent sections.

Following the end of the 2013 field season, local colleagues continued to monitor the wall—wetting and photographing daily for an additional 2 weeks during the dry season. Thereafter, the wall was inspected on variable intervals (2–3 times per week, once per week, once every other week). Throughout this period, we were in regular discussion with our collaborators and made protocol adjustments based on their observations and knowledge of the environment. This dialogue was critical and resulted in the removal of the plastic covering 4 weeks after the date originally

Figure 6. Tekelioğlu experimental L-shaped mudbrick wall: (a) just after construction in July 2013 (southeast side) and (b) 11 months later in June 2014 (southeast side).

scheduled due to unexpectedly high temperatures. The wall stabilized in November 2013 and remained in place with very little damage until March 2014, when grazing cattle caused significant damage. Following this incident, our local partners partially reconstructed the wall. Assessment in June 2014 (Figure 6(b)) indicated substantial color alteration and complete failure of all mud coatings applied between mudbrick courses, despite the high Ca-content of soils used. This is unsurprising as the mud coatings did not contain added binders (lime or cement) and reflects the need for semiannual (or more frequent) maintenance—critical information for preservation planning of the archaeological site. While we observed significant structural instability, most damage could be attributed to the April event when referencing our archive of digital documentation condition images.

4.5. Testing of soft-capping methods

Soft-capping methods for mudbrick architecture were tested at both Eski Hacıveliler and Tekelioğlu. These experiments provided integral data regarding locally available turf-building plants that are suitable for use. We applied test caps to a collapsed mudbrick wall at the Eski Hacıveliler schoolhouse complex and the test wall constructed in Tekelioğlu—sites that differ in both elevation and exposure. The contrast between conditions and their impact on preservation interventions at these two sites is important, as Kaymakçı is predominantly devoid of large vegetation except for localized areas of scrub oak. Furthermore, the site covers a range of elevations from the highest part of the citadel in the north to the extended lower terraces near exterior fortification walls in the south. Finally, exposure to temperature extremes between the 2013 and 2014 seasons provided a window into possible maintenance requirements if implemented at Kaymakçı.

4.5.1. Soft capping at Eski Hacıveliler

Soft capping experiments at Eski Hacıveliler tested vegetative capping materials applied to horizontal and vertical/near vertical mudbrick surfaces secured to a stone foundation. The soft vegetative cap incorporated the following layers placed on top of premoistened mudbricks in this order: mud coating, fine sand, geotextile, mud coating, gravel, mud coating, and vegetation (Figure 7). Following daily wetting and photo-documentation, the completed cap slowly dried for the following 15 days. This process of daily wetting and photographing continued at varying intervals until the end of the dry season. From mid-September 2013 to May 2014, the soft cap was watered and photographed weekly to document changes and characterize the cap's ability to protect the underlying mudbricks. Unsurprisingly, the Eski Hacıveliler vegetative cap was unattractive in appearance and vertical/near vertical areas failed to achieve robust plant growth. According to images and verbal reports from collaborators, the vegetation component began to fail on the southern side as early as January 2014. This makes sense given the northerly winds associated with the site. In subsequent months, vegetation on the south side detached from most vertical surfaces. Furthermore, evidence of small mammal or insect damage appeared at the interface of the mudbrick with the stone-masonry substrate.

Figure 7. Soft vegetative cap applied to vertical and sloped surfaces of mudbrick (north side) at Eski Hacıveliler.

Figure 8. Soft vegetative cap applied Tekelioğlu experimental L-shaped mudbrick wall (top surface) directly after application.

4.5.2. Soft capping at Tekelioğlu

In contrast to the Eski Hacıveliler field trial, the soft cap system only protected the top horizontal surface of the experimental mudbrick wall in Tekelioğlu. Prior to installing the cap, thin sedimentary stones were set perpendicularly along the wall perimeter for protection using a lime–cement–soil–sand mortar mixture (5:1:2:6) using T4 soil. Following setting of the stone perimeter, we placed soft vegetative cap layers on top of the mud-coated, premoistened mudbricks using sand, geotextile, gravel, mud coating, gravel, dry soil, and vegetation (Figure 8). The completed cap was wetted, documented, and covered with a wet towel and plastic sheet to control drying. Local collaborators remoistened the towels daily for 15 days and at varying intervals thereafter, until the end of the dry season.

Based on observations and the advice of local collaborators who monitored the high temperatures, we extended slow drying of the soft cap through the end of August. This modification to the maintenance protocol was critical for the success of the cap, as was the careful monitoring. In early September, winds caused the vegetative layer of the soft cap to separate completely from the wall. Local collaborators successfully replaced the vegetative segment and stabilized it through careful watering, application of protective plastic layers, and ongoing monitoring. The soft cap and mudbrick wall stabilized in November 2013 and remained in place until grazing cattle significantly compromised the wall's stability in March 2014, necessitating its partial reconstruction, as mentioned above. This disturbance rendered observations of the soft-capping after this date unremarkable.

4.5.3. Future soft capping at Kaymakçı

Excavations at Kaymakçı have been carried out each year since 2014 with the exception of 2017, which was a study season. Ongoing excavations adopts an open-area approach, which uncovers large horizontal extents (20 m by 20 m in most excavated units) and enables easier recognition and understanding of large architectural features (Roosevelt et al., 2018). Because of this practice, most excavated areas are still relatively shallow. Only limited traces of mudbrick architecture have been exposed so far, comprising single mudbricks either inserted into or sitting atop stone foundations, mudbricks in secondary and tertiary contexts, an isolated stretch of mudbrick superstructure preserved under a fallen fortification wall, and small collapsed wall deposits with mudbricks and stones intermixed together. It is hoped that continued excavations in deeper stratigraphic layers will reveal better preserved earthen architectural materials, protected from erosion, and anthropogenic activities since antiquity.

5. Discussion

Mudbrick traditions persist for thousands of years in the Gediz Valley—demonstrating the continuing value of mudbrick in both ancient and vernacular architecture. Preservation of these resources requires an integrated approach that draws on multiple lines of evidence and requires substantial collaboration with local stakeholders for effective results. Careful assessment of raw material procurement and processing, technology and manufacture practice, use, maintenance, and abandonment bears consideration within the context of past and present human agency during interactions with the surrounding environment. Participants will easily draw substantive and meaningful observations regarding the connections between ancient and current architectural practice and maintenance when research incorporates both archaeological and ethnographic investigations.

Data (physical, chemical, and mechanical) collected from ancient and recent contexts provide insight into the process of selecting/processing raw materials, as well as making mudbrick. Furthermore, they help predict deterioration and interactions with changing environments during use, discard, and recovery. When considered on its own, the data collected from excavated mudbrick at Kaymakçı are limited severely by the poor preservation of extant mudbrick and the perishable nature of the superstructures themselves. Based on extant bricks and brick fragments, it is possible to characterize particle composition and size range, as well as begin to define average brick size. However, it is difficult to consider mudbrick function and decision-making made during manufacture and use in the past without understanding the surrounding geology, or, the chemical, physical, and mechanical properties of local sediments within the context of vernacular architectural practice. Furthermore, phenomenological concepts of weather and environment provide insight into expected/unexpected damage, as well as maintenance efforts to mitigate those events.

These experimental results indicate that locally available resources are critical to the successful implementation of preservation practice. As has been demonstrated at Gordion (Goodman, 2002; Miller & Bluemel, 1999), Ḫattuša (Seeher, 2007), and Kaymakçı, the importance of local partners with knowledge of native plants (and other resources), as well as seasonal weather is critical for the successful implementation of these conservation interventions. They also identify avenues for future research and confirm that application of soft vegetative caps to non-horizontal surfaces is challenging and ineffective. Equally important is the implementation of long-term and intensive monitoring throughout the year to ensure that interventions such as soft vegetative layers survive, requiring close cooperation with local partners. Efforts to develop solutions for mudbrick walls that do not have or cannot be modified to have a relatively horizontal surface are necessary. The ability to balance presentation of original architecture with an applied sacrificial surface will be critical.

The multipronged approach combining conservation, archaeological, and ethnographic expertise has proved extremely valuable for the study of mudbrick at Kaymakçı in terms of identifying necessary requirements for year-round maintenance of mudbrick architecture. The examination of the abandoned village of Eski Hacıveliler combined with experimental mudbrick wall building and cooperation with local collaborators have beneficially informed the study of ancient immovable architecture at the site of Kaymakçı. While at Kaymakçı we have excavated only limited courses of poorly preserved *in situ* mudbrick to date, the experiments and the study of vernacular architecture highlight that mudbricks can function as optimal building media in an environment with strong seasonal winds and rain. The structures at Eski Hacıveliler age relatively slowly without any maintenance of the buildings themselves—particularly those located in areas protected from wind. Moreover, the experimental wall at Tekelioğlu showed that mudbrick is robust enough to withstand unfavorable weather conditions, as long as structures undergo a seasonal maintenance program implemented through collaboration between all stakeholders. When combined, archaeological, ethnographic, and preservation approaches provide valuable insights connecting human activity in the ancient and recent pasts, while at the same time ensuring that mudbrick architectural materials survive within their archaeological and vernacular contexts.

Continued collaboration with local stakeholders necessarily requires capacity-building through development of explicit training opportunities. While participants from surrounding villages work and develop their excavation skills seasonally, preservation training is often ad hoc during field seasons and limited to excavation closing protection protocols. Future efforts will focus on bespoke training opportunities in hopes of building capacity for ongoing preservation of the site and region.

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Notes

1. Please note where possible measurements for mudbricks are reported to the millimeter. In some cases, this was not possible due to the limitations of published information.
2. Cement mortar mixes required a greater proportion of water to achieve the best working properties, while less water was required in the lime and cement–lime mortars. Prior to application, all surfaces were cleaned of detritus and sprayed with water to ensure good adhesion. Mortar was applied into all interstices by hand and allowed to partially set. Depending on weather conditions, this stage was reached within 30–60 min. The mortar was then compacted with a rubber hammer to eliminate any voids/bubbles and minimize cracks. The compacted mortar was abraded to create a rough and porous surface using medium pressure and spatulas. Mortar surfaces were then shaped to remove any extant lips and reduce risk of water infiltration.

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